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Generic Build Strategy - A Preliminary Design Experience

James R. Wilkins, Jr., (M), Wilkins Enterprise, Inc., U.S.A. Perry Singh (AM), Advance Marine Enterprises, Inc., U.S.A., and Todd Cary (AM), Naval Sea Systems Command, U.S.A.

ABSTRACT

From the very inception of the Preliminary Design phase of the U.S. Navy's new amphibious assault ship, which at the time was designated only as the LX, there has been an emphasis on generating a design which is producible; one that requires a minimum of redesign by the building yard and which can be built efficiently using modern ship construction techniques. This emphasis resulted in establishment of a Producibility Task Manager as a member of the LX Preliminary Design Team and in the creation of a Product-Oriented Design And Construction (PODAC) Working Group. The functions of this Group were to mimic a shipyard production planning effort and to interact with the Design Team on a regular basis. This paper describes the results of their efforts, including the development of a Generic Build Strategy (GBS) and numerous Design for Producibility improvements during the LX Preliminary Design Phase.

NOMENCLATURE

The nomenclature used throughout this paper complies with that in use in most of the National Shipbuilding Research Program (NSRP) documentation and with that used in Reference 1. No attempt is made herein to describe elements of the Zone-Oriented construction processes or procurement processes used in current day shipbuilding, since these matters are thoroughly covered in numerous other NSRP documents.

BACKGROUND

Use of a GBS has been proposed as a means to incorporate ship production considerations into the early stages of naval ship acquisition with the objective of reducing ship acquisition cost. Any world class organization developing and acquiring a new item requires the concurrent development of the product design and the process by which the product is fabricated and/or assembled. During the feasibility study, preliminary design and contract design phases of ship design, namely the early stages of ship acquisition, there are not only systems engineering benefits of having a GBS, but there are also potential benefits to program management efforts.

The Navy's early stage ship design management, recognizing that changes in the design process were necessary in order to respond to the changed ship construction methods used in the nation's shipbuilding yards, assigned a Producibility Task Manager to the team that was assembled to develop the Preliminary Design (PD) of the LX. His responsibilities included overseeing and driving design for production efforts as a part of general acquisition cost reduction efforts. Since an inherent part of designing a ship to be most producible is to have a reasonably good idea of how it will be built, one of the major tasks of the Producibility Task Manager was to develop a GBS. That is, in addition to emphasizing the need to design the ship to be more producible, it was necessary to provide the designers with a general idea of how the ship would likely be built. This build strategy would necessarily be

generic, in that it could not be oriented to the unique capabilities of any one of the several shipyards that would be expected to bid for the construction contract. Nevertheless, this generic build strategy was expected to reflect the actual current capabilities of U.S. shipyards in order to effectively evaluate the impact of design decisions on ship production and to leverage the design efforts towards a more producible and cheaper acquisition cost. This effort was the first application of the concept of development and use of a GBS for a U. S. Navy in-house early stage ship design.

PODAC WORKING GROUP

The LX Preliminary Design effort was initiated in the second quarter of FY '93 at a Navy collocated design site. This phase of the design was divided into five design iterations, with the last iteration of the design to be completed during the first quarter of FY '94. During PD, no shipbuilders were under contract to support development of a GBS, so, under the leadership of the Producibility Task Manager, a simulated ship production department was assembled using experienced non-shipyard-affiliated ship production experts. This "surrogate shipyard", more formally called the Product-Oriented Design And Construction (PODAC) Working Group, was established in June 1993 to mimic a shipyard planning effort, and to interact with the LX ship designers and engineers during PD. This group was comprised of members who had firsthand knowledge of the amphibious ship construction process and who possessed an understanding of modern (advanced) ship construction practices.

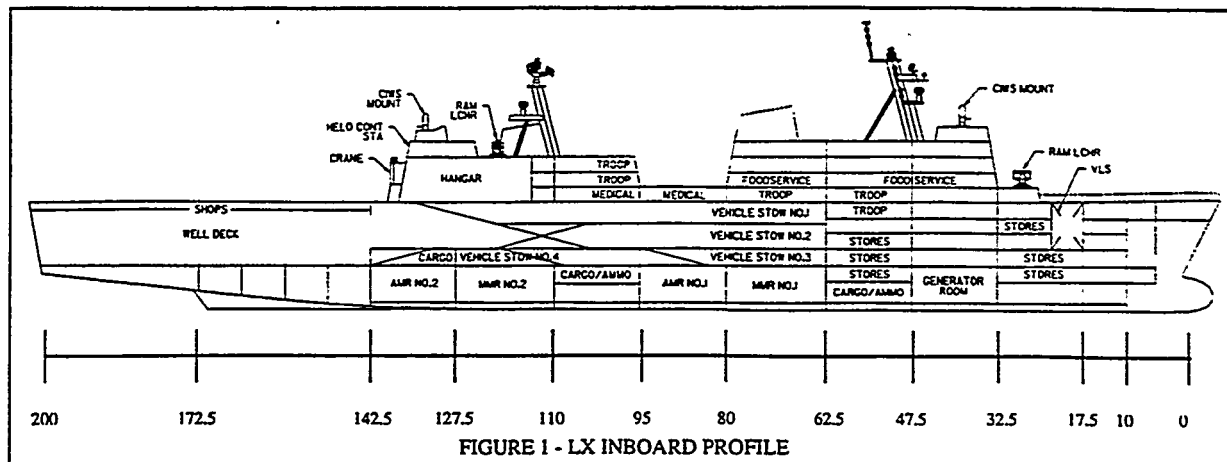
One function of the PODAC Working Group was to interface with the ship design team during PD, and, by introducing ship design for production concepts early within the various design disciplines, to guide the achievement of

a more production-friendly design. Navy ship designers, especially during the early stage design, are typically isolated from production facilities, working either at a design agent's office or a Navy collocated design site, under short deadlines and to stringent operational requirements. The PODAC Working Group was tasked to enhance the design team's capabilities by "thinking" for the design team as a shipyard would think if the design were being done at the shipyard.

From the inception of the early design stage effort it was intended that shipbuilders be given the opportunity to participate in evaluations of the Contract Design (CD) of the ship, through the use of on-site representatives and funded support for design evaluations, specification reading sessions and studies of detailed aspects of the design as it proceeded. It was intended from inception of the design that the GBS developed by the PODAC Working Group would be made available to the shipbuilders for their critical analysis, suggested changes and identification of any specific aspects of that strategy which would degrade their ability to compete equally for the shipbuilding contract and build the ship for minimum cost.

It has never been the Navy's intention to impose the build strategy upon the shipbuilder. One of the primary purposes of the involvement of the shipbuilders during the CD process was to identify aspects of the design, that would negatively impact the competitive aspects of building it. The primary purpose of the GBS was to help ensure that the design generated through CD would be capable of being built efficiently without major redesign efforts by the successful shipbuilding contractor.

The PODAC Working Group accomplished three primary functions during the Preliminary Design phase. They developed a Generic Build Strategy, which was used as a guide in



evaluating and revising the location and configuration of spaces in the General Arrangement Plan and in the structural design of the ship. They provided Design for Producibility guidance to the system designers in developing system details and arrangements that would enhance the producibility of the systems without negative impacts on maintainability or operability of the systems. In addition, the team provided some cost estimates based on work content instead of weight, as guidance to NAVSEA cost estimators in assessing the results of design modifications. The approach to each of these three efforts and the major results are analyzed in the following sections.

Figure 1 shows the PD inboard profile of the LX. Frames are numbered from the bow aft, based on the number of meters from the forward perpendicular. Thus Frame 100 is amidships. At the end of PD, the LBP and LOA of the ship were 200m and 208.4m, respectively, with a beam of 31.9m.

GENERIC BUILD STRATEGY DEVELOPMENT

General

The major part of the PODAC Working Group's efforts were directed toward the identification of design features that would enhance the ability of any prospective shipbuilder to build the ship in a logical fashion using modern Zone-Oriented construction techniques. Since significant savings can be realized during Detail Design if a shipyard receives a Contract Design arrangement that recognizes where construction joints will be located and ensures that minimum interferences with those welding paths are created, a Generic Build Strategy was developed by the PODAC Working Group. This strategy was considered *generic* in that it was intended to result in a design that would be capable of being built efficiently by any of the potential

DESCRIPTION OF THE SHIP

The LX (since designated the LPD-17) is the U.S. Navy's next generation Amphibious Transport Dock ship with a primary mission to embark, transport and debark marine landing forces in assault by helicopters, LCACs, and assault amphibious vehicles. It is intended to be a functional amphibious lift replacement for 41 ships of the LKA 113, LPD 4, LSD 36 and LST 1179 Classes. In early PD it was established that the design was to be hybrid metric.

builders without major changes in their production facilities.

The first step taken in the development of a build strategy for the LX was to identify the major zones which would likely control the construction process. The inputs to this process were the first draft of the General Arrangement and Midship Section drawings. The General Arrangement Drawing included the Inboard Profile shown in Figure 1, an Outboard Profile and plan views of each deck.

These documents were used to identify the major zones of the ship and then, with a set of block break criteria established by the team, to identify the block breaks. A block numbering sequence was developed that related each block to a location in the ship. With the block breaks identified, a notional block erection sequence was identified. By putting a time scale on that sequence and utilizing historical time frames between block erections, an erection schedule was developed. A list of major equipment was developed. The block into which each piece of major equipment was to be located was determined. By correlating the lead time for the various elements of the equipment procurement process with the block erection schedule, it was possible to develop an equipment installation schedule and a first cut at the dates by which major equipment would have to be ordered. This information could be used to identify what long lead equipment, if any, would have to be ordered before the shipbuilding contract is awarded in order to minimize the time of the shipbuilding process. A more detailed description of each of these elements of the Generic Build Strategy follows:

Zone Identification

In commercial ships the machinery space is normally a single space located aft, the accommodations (for the small number of crew

members) are all located above the main deck in a separate deckhouse and the rest of the ship is configured for the type of cargo that the ship is to carry. It is common practice to identify each of these portions of the ship as a separate zone; namely the Machinery Zone, Accommodations Zone and Deck Zone. Each of these three major zonal volumes of the **ship** entails significantly different functions, complexity of construction and material ordering requirements, as a result of different design requirements. Therefore, it is customary to treat each of them as a separate zone, and to assign to each, separate design teams who are familiar with the peculiarities of construction of that zone.

The entire ship is considered as a fourth zone, since certain work can be done most efficiently onboard the ship before or after it is being erected. Where the work in a particular area of the ship is more complex than that in another area of the ship, that particular part of the ship may be treated as a separate zone or subzone.

In military ships, where, largely for survivability reasons, there normally are multiple machinery spaces, and where accommodations (for much larger crews) are spread throughout the ship, the identification of the basic three types of zones is not as straightforward. Zones can be identified, but several functions may exist within each zone. In the case of the LX, with the configuration shown in Figure 1 as a given, the PODAC team identified the following zones.

Machinery Zone. The machinery spaces contain many large, heavy pieces of equipment arranged in relatively dense configurations, involving major distributive system interfaces. On the LX, the Machinery Zone was taken to be the volume extending from Frame 62.5 to 142.5 longitudinally and from the keel to the 01 Level vertically. This volume includes the

two Main Machinery Rooms and the two adjoining Auxiliary Machinery Rooms.

Deckhouse (Accommodations) Zone. All volume above the 01 Level was treated as a single zone. Although there are few accommodations in this volume, it was treated as a separate zone, primarily for convenience, since it is above the strength deck. For this ship; this zone is not significantly different in most production considerations than the rest of the ship outside the Machinery Zone.

Hull Zone. Although the rest of the ship below the 01 Level would therefore be considered the Hull Zone, on the LX, because the Machinery Zone separates the forward portion of the ship from the stem, the after portion of the ship was treated as a separate zone. The forward portion of the ship was treated as two separate zones because the work in the bow area, forward of the bulkhead at Frame 17.5, is significantly more difficult to construct than the volume between Frames 17.5 and 62.5.

SubZones. Each of the zones on the ship was further subdivided into subzones, based primarily upon the location of transverse bulkheads, recognizing that these bulkheads would be used ultimately to establish the boundaries of hull construction blocks and this subdivision would be used in the block numbering sequence.

Zone Numbering. The zone from the bow to Frame 17.5 (a Hull Zone) was identified as Zone 1000. Two subzones were identified as 1100 and 1200; the division being at Frame 10.

The volume between Frames 17.5 and 62.5, from the keel to the 01 Level, was identified as Zone 2000, with Subzones 2100, 2200 and 2300 separated by Frames 32.5 and 47.5. Although Zone 2000 includes a generator space, the configuration of this portion of the ship is sufficiently different than that of the volume

forward of it and of the portion aft, that it was treated as a separate zone.

The Machinery Zone was designated Zone 3000, with Subzones 3100, 3200, 3300, 3400 and 3500 separated by the transverse bulkheads at Frames 80, 95, 110, and 127.5.

Zone 4000 extends from just aft of the bulkhead at Frame 142.5 to the stem and includes cargo carrying and line handling areas. It is separated into Subzones 4100, 4200, 4300 and 4400 by transverse bulkheads at Frames 157.5, 172.5 and 187.5.

Zone 6000 is comprised of the volume above the 01 Deck. In an earlier version of the ship's topside conjunction there was a Zone 5000. An arbitrary decision was made to leave the 6000 zone designator unchanged when Zone 5000 was eliminated

Block Identification Considerations

Because modern shipbuilding techniques involve construction and outfitting of the ship in major three-dimensional assemblies conventionally called blocks, one of the most essential elements of a build strategy is the identification of the boundaries of each of those blocks. All elements of the entire construction, outfitting and ship erection sequencing (the primary elements of a build strategy) are built around the definition of the blocks. For a ship design to be a producible design, the arrangement of spaces and locations of equipment must take into account the block break locations.

This is also the area where individual shipyards, with different facilities or different construction philosophies, may have significant differences in approach. The ability to create a generic build strategy that does not penalize specific shipyards is dependent upon selecting locations for block breaks that are

logical and based upon actual current ship-building practices and shipyard capabilities.

The PODAC Working Group recognized the following elements as affecting the definition of block break locations and block sizes:

. To provide the structural stiffness required for transporting and lifting blocks, it is normal for one end or side of a block to be located close to, but not at the location of a transverse or longitudinal bulkhead or deck. To facilitate the welding of this end or side to the adjoining block during erection, the erection joint is located roughly 300 mm (6 -12 inches) from the bulkhead or deck and the stiffeners are located on the opposite side of the bulkhead or deck from the erection joint.

Normally, one end or side of a block is "hard," meaning that the stiffeners are welded to the plate all the way to the extreme end of the block while the other end or side is "soft" with the stiffeners remaining unwelded for the last half meter (say 18 inches). This allows the stiffeners of the "soft" end to be aligned to those of the adjoining block more readily during erection. The "hard" side normally is the side near the bulkhead or deck of course.

. To facilitate as much installation of under-deck items such as pipe hangers, piping, electrical wireways, ventilation ducting, etc. as possible prior to erection, the block breaks are normally made roughly 200 mm (3 -6 inches) above a deck. The completed assembly can then be turned right-side-up and landed in place on top of another block.

Given the above considerations, in defining block boundaries it is necessary to consider

- . Location of major longitudinal bulkheads and other major structures.
- . Transverse bulkhead spacing.
- . Length and width of plates available from steel manufacturers.

- Maximum weight and size of outfitted blocks which can be handled and transported in a yard.

- . Amount of pre-outfitting to be accomplished in the block before erection.

- An effective method of erecting the blocks.

Block Break Criteria

The following criteria were established by the PODAC Working Group as standards, to be altered only when some particular characteristic of the structure or arrangement could be shown to override the producibility aspects of the construction sequence:

- . All block breaks would be above the deck and aft of a transverse bulkhead.

- . All stiffeners on transverse bulkheads would be located on the forward side of the transverse bulkhead, wherever practicable.

- . Blocks would extend from each major transverse bulkhead to the next.

- . Block widths would not exceed 10 meters.

- Block heights would be one deck high, except along the sides of the ship and in the bow, where space arrangements permit multiple deck high blocks.

Block Break Definition

optimization of plate width or plate length was not actively considered in the development of the block break plan. Instead, the Group was confined to finding a logical block break scheme within the constraints of the design that had been developed to meet the operational requirements.

For this initial effort the most immediate concern was the distance between major subdivision bulkheads. Except for the Main Machinery Rooms (MMRs) this distance is 15 meters (approximately 49 feet); very near the maximum plate length traditionally available from steel manufacture without special orders. The MMR bulkhead spacing may require piecing of plate lengths, but this was accepted for the PD, awaiting further comment from shipbuilders during their CD participation. The major subdivision locations were established prior to and independent of the block break scheme outlined here, having been selected during the feasibility design stage.

Throughout PD no significant shell straking effort was undertaken, with the exception of locating the crack arrestor plating.

Block Width Bottom Shell and Inner Bottom. In the block break plan, the double bottom of the ship is generally broken transversely just inboard of each wing wall and 1.5 meters outboard of the CVK to accommodate the standard 3 meter plate width flat keel. At its widest point the distance between wing walls is 19 meters. Therefore, one inner bottom block is approximately 8 meters in width, while the other is 11 meters. These can be fabricated from combinations of plates of 2 meter width and 3 meter width.

Block Width: Interior Decks. For the decks above the inner bottom, each hull block includes the half width deck inside the wing walls and the bulkhead(s), stanchions and associated structure beneath the deck. The straking scheme and widths selected for plates are as described above.

Side Block Dimensions. The Well Deck and Vehicle Stowage Decks extend through two thirds of the ship length. As described later in the paper in the section on parallel shaping of the hull, the shape of the shell for virtually the entire length of the ship represents parallel sections of flat plate with identical cross sec-

tion. For much of this length the wing walls of the well deck and vehicle stowage decks are straight. Consequently, the block breaks along this entire length of hull are just inboard of the wingwall and just aft of the transverse bulkheads. Inmost of this length of hull, the blocks were selected to be two decks high, partly because tank structure and tank dimensions dictated the selection of block breaks in the lower portions of the area and partially because of the customary construction practices in U.S. shipyards.

Block Numbering Scheme

Although a block numbering system is a relatively trivial concern, in that almost any consistent numbering system will meet the needs of the shipyard and certainly has no effect on the early stage design development the PODAC Working Group developed a four-digit numbering scheme for the blocks.

The first digit identifies the zone in which the block is located. (i.e. 2xxx for Zone 2000)

The second digit identifies the subzone in which the block is located. (i.e. 21xx for the first subzone in Zone 2000)

The third digit identifies the deck level of the topmost deck in the block. The Inner Bottom was identified as deck level 1, the 2nd Platform as level 2, the 1st Platform as level 3, 2nd Deck as level 4, and so on. For blocks which are more than one deck high, the highest deck level was used for numbering the block.

The fourth digit identifies the transverse location of the block with 1 being the inboard starboard block, 2 being the inboard port block, 3 being the outboard starboard block (since there were never more than two blocks on either side of centerline) and 4 being the outboard port block.

Block Break Drawing

After identifying the block breaks by marking up the general arrangement drawings, an isometric drawing was prepared to provide a visual description of the results of the effort. The LX product model sub-division model was used as the basis for development of the block break plan. Using the criteria described previously, the LX was divided into 186 blocks; 7 in Zone 1000, 33 in Zone 2000, 95 in Zone 3000, 38 in Zone 4000 and 13 in Zone 6000.

BLOCK ERECTION PLANNING

Having the blocks defined and numbered, the next step in the development of a building strategy is to produce the schedule by which the blocks will be erected at the building site. This effort is not critical for the development of a PD, but was felt to be of use for assessing where Navy resources might best be expended in additional design development.

Block Erection Sequence

When developing the block erection schedule, the PODAC Working Group found it helpful to develop a notional block erection sequence. The technique used by the PODAC Working Group is described below, but is recognized as only one possible way to achieve the same objective.

A table, similar to that shown in Table I, was prepared. Each column represents one subzone of the ship. The subzone numbers were listed at the top of each column. In each column, all of the block numbers in that zone

were listed from top to bottom in the order in which they would be erected.

On a separate sheet, using the same general format, the sequence of joining each of the blocks was laid out. The numbers of the first blocks to be erected were placed in the top-most horizontal line, located directly below the subzone of which the blocks were a part. The numbers of the next blocks to be erected were placed in the next horizontal line, directly below their own subzone numbers. This process was continued working down the page in the order in which each set of blocks would be joined to the blocks in the preceding horizontal row. Table II illustrates the form of the table that was generated. A spacing of two lines was placed between sequential blocks in subzone 3300, from which the erection process initiated so that the fore and aft sequencing of block erection would not be obscured.

Block Erection Schedule

The final step in the process of developing the block erection schedule is to evaluate the number of weeks required between each of the blocks in one horizontal line and the blocks in the next lower horizontal line, thus converting the vertical dimension on the page to a time scale. The scale can be measured in terms of weeks after erection of the first block or weeks before erection of the last block or both.

Since the overall time between erection of the first and last blocks is but one part of the total detailed design and construction period of a ship, estimates also must be made of the time span between Contract Award and the erection date of the first block and of the span from erection of the last block to delivery of the ship. The sum of these three values is the total ship construction duration that must be allowed for in a prospective ship owner's

LX SUBZONE NOTIONAL BLOCK ERECTION SEQUENCE CHART

planning. It is then possible to convert the time scale on the block erection schedule to weeks before delivery or to weeks after contract award. Both of these sets of values are useful in acquisition planning.

LONG LEAD EQUIPMENT SCHEDULE IMPACTS

Procurement of Long Lead Time (LLT) material is a significant part of the preconstruction effort in shipbuilding contracts. For the purpose of this study, equipment having manufacturing lead times of 12 months or more were considered LLT items.

The Navy's historical material data base maintained by NAVSEA Shipbuilding Support Office (NAVSHIPSO) was used to develop a list of the major equipment on the ship and, from that, to identify the LLT items. For planning purposes, worst case lead times based on historical data from recent amphibious assault ship construction programs, such as the LSD 44, were used.

The first step in developing the LLT schedule was to identify the block into which each item will be located. In cases where identical pieces of equipment are located in several blocks, each of those blocks must be included in order to determine which of them requires the earliest in-yard receipt. For each LLT item, an estimate was made of the time duration before or after block erection that the item must be ready, based on experience with past shipbuilding programs.

Estimates for durations of each of the following activities in the procurement cycle were made (further explanation of these activities is found in Reference 2):

1 Preparation of Requests for Quotation (by the shipyard),

. Preparation of offers (by vendors),

. Evaluation of offers, approval and negotiation (resulting in purchase order issue),

. Manufacturing lead time (including shipping),

1 Shipyard receipt inspection

1 Preparation for installation.

When the sum of these durations is subtracted from the block erection date (measured in months after contract award), a positive resultant means that the procurement process can begin after contract award. When the answer is negative, however, it means that the procurement process for the equipment must be initiated by the ship owner before the shipbuilding contract has been awarded. There are several options available to a ship owner to accomplish the procurement of such equipment, but it is important that this information be known as soon as possible so that the acquisition strategy can reflect this need.

The overall detailed design and construction schedule selected for the LX by the program office was such that no LLT material and no advanced procurement contract was required.

USE OF THE LX GBS

One of the results of the LX PODAC Working Group effort is an internal NAVSEA document reporting on the results of the study and describing the methods used in developing the LX Generic Build Strategy. This document, after being updated during the Contract Design period as a result of evaluation by the shipbuilders, will serve as guidance to future NAVSEA ship design efforts in development of a GBS for their programs. However, there were direct benefits to the LX Design Team as well.

LX NOTIONAL BLOCK ERECTION SEQUENCE CHART														
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		4243			3431		3231		2321					
		4244			3432		3232		2322					
	4343			3531				3131		2221				
	4344			3532				3132		2222				
4443				3530		3351			2341					
4444						3352			2342					
					3473		3273			2241				
					3474		3274			2242				

7-11

General Arrangements - Several changes were made to the General Arrangement of the LX in response to the location of block breaks.

. Transverse passageways were moved to the after side of transverse bulkheads, to thus minimize the number of longitudinal bulkheads that would exist in the way of a block erection joint.

- ☆❖❑ locks, escape trunks, etc. were relocated to the forward side of transverse bulkheads, to remove these complex structures from being directly in the way of erection breaks. This also allows them to be completed during the block construction period rather than having to be constructed on board after the block erection, thereby saving both time and labor-hours in addition to improving quality.

Structures - Numerous recommendations were made to the structural design as a result of considering the location of block breaks and erection joints.

- Stiffener Location - Stiffeners on transverse bulkheads were placed on the forward side of the bulkheads to achieve compatibility with anticipated block breaks aft of the bulkheads. Later, as the Preliminary Design structural details became available, the block break at Frame 32.5 was shifted to a location forward of the frame. This was necessary in order to allow the stiffeners to be located on the after side of the bulkhead in line with the stiffeners in the superstructure, the forward bulkhead of which is located at Frame 32.5, as can be seen in Figure 1. This led to a decision to locate the erection joint at Frame 17.5 to the forward side of the bulkhead, also, in order to have that bulkhead part of each block in Subzone 1200.

. Bilge Radius Joint- In the original mid-ship section drawing, the longitudinal butt weld for the crack arrestor strake at the bilge radius joint was located outboard of the longitudinal bulkhead that is in line with the wing-wall throughout the length of the ship. Since

the erection joint for all of the blocks along the wingwall will be inboard of the longitudinal bulkhead the weld location was changed to align with the block break, thus eliminating an extra weld along virtually the entire length of the ship on both sides of the ship.

DESIGN FOR PRODUCIBILITY

Even before the PODAC Working Group was created, the LX Design Team had established Producibility as a major design goal and, as stated earlier, had assigned a Producibility Task Manager. His responsibility included review of all elements of the design, to identify areas where design changes could reduce cost without changing the functionality of the design - functionality being understood to include maintainability and reliability as well as operational functionality. Some of the design changes that were made while not apart of the GBS effort per se, were done keeping the ship construction process in mind.

Hull Form Simplification Efforts

The hull form used at the beginning of PD was a conventional hull that had been developed based upon the LSD 41 class and on hull form energy efficiency work done during the AE-36 preliminary design. The intention was to develop a producible hull form based on this design. The hull form design team with input from the PODAC Working Group and from past hull form producibility efforts, proceeded to eliminate or simplify the curvatures in the hull. The areas of the shell above the waterline received the primary attention, but some changes were made to the underwater structure as well. The following changes were introduced:

Straight Frames. Curvature was eliminated to the maximum extent in frames forward of Frame 95. Only a few sections at the very forward portion of the bow are curved above the waterline. Similarly, a significant effort was made to obtain straight frame sections forward of Frame 95 in the region above the 9 meter waterline.

Bulbous Bow. The LX hull form features a bulbous bow which, though optimized hydrodynamically, incorporates some characteristics believed to be beneficial from a producibility standpoint. A knuckle is formed at the bulb-to-hull intersection in order to avoid the tight and complex curvatures associated with a fillet. Furthermore, the bulb contains sections which are, for the most part constant born Frames O-5.

Sheer and Camber. The decks have no sheer aft of Frame 25, where the forward section of superstructure intersects the 01 Level. Forward of Frame 25, the sheer is a straight line in the profile view. With the sheer providing ample allowance for water to flow off the deck, there is no need for camber. Thus there is no camber on any of the decks.

Flat of Bottom. The LX hull form incorporates a well defined flat of bottom region extending approximately from Frame 10 to Frame 125. Aft of this, a cylindrical (and therefore developable) "bottom plate" forms the transition into the flat half-siding.

Parallel Midbody. Parallel midbody has been provided in the amidships area, between Frames 95 and 110. Although this is only a single watertight subdivision, the parallel section extends beyond each of the two transverse bulkheads involved to allow for simple construction.

Skeg. The centerline skeg on the LX hull form consists of single curvature plate. It abuts the hull, forming a knuckle at the skeg/hull intersection.

Parallel Hull Shape. The shape of the LX hull above the third deck is identical in cross section from Frame 95 aft i.e., for more than half the length of the ship. Moreover, that shape is composed of all fiat plate sections, with a horizontal knuckle that is located above the second deck, at the anticipated location of a block break. Similarly the shape of the side shell between the 1st Platform and the Third Deck consists of flat panels of identical cross section for about 1/3 of the length of the ship.

Ruled Surfaces. Ruled surfaces were used in the region aft of Frame 110 below the main knuckle and above the design waterline.

Deck Edge. In profile, the LX hull form features a horizontal deck sheerline from the transom to Frame 25 at which point there is a knuckle in the deck sheerline and then straight sheer to the stem. In plan, the deck edge is straight and parallel to the centerline from Frame 47.5 to the stem. From Frame 47.5 forward to Frame 25, it is straight, then fairs into the stem in a convex curve.

Flat Plate. The entire region above the main knuckle consists of flat plate as does the raked transom.

Crack Arrestor. Consideration of the location of the crack arrestor joint raised the question of whether crack arrestors are needed on modern ships given the fact that the composition of steels used for ship construction has been changed greatly since the W.W. II era. As a result of this question, a study has been initiated to evaluate the requirements for crack arrestors in modern warships. If the need for crack arrestors is validated, the study will begin to look for more production friendly materials that might be used for this function in the future.

The improvements described above were made with the expectation that production man-hours for hull construction will be significantly reduced and that there will be addi-

ional labor and material savings through the decreased extent and complexity of jigs and fixtures required for forming and joining the hull and superstructure. An estimate of the anticipated cost savings was made, using the techniques described in References 3 and 4. A reduction of 10-15% of the man-hours used to construct the shell plating of the hull was predicted.

System Simplification

One major simplification effort made during the Preliminary Design stage was to use zonal distribution systems for the electric power and lighting systems.

In warships design, electrical equipment is designated as either vital or non-vital. Vital equipment must be capable of being powered from one of two independent sources or switchboards. Non-vital equipment need only be powered from one source.

In the initial phases of PD, there were two main switchboards, one located in the forward part of the ship and the other located aft. The distribution systems for non-vital systems were run from the equipment to only one of those main switchboards. Vital system equipment was connected to both switchboards. This approach has been designated a radial distribution system because all distribution runs radiate out from the main switchboards.

The zonal approach uses two main distribution buses running the entire length of the ship, both of which are connected directly to the main switchboards through load centers located in the buses. The ship is segregated into several zones, in each of which there is one load center in each bus. All equipment located in a zone is connected to one (non-vital systems) or both (vital systems) of the load

centers in the zone. The net result is significantly less length of electric cabling, simpler and shorter wireways, and many fewer penetrations of decks and structural members.

The studies have shown that the zonal approach results in a significant material and consequently, a weight savings. However, the labor reduction is not proportional to the weight reduction since there is no change in the number of equipment hookups that must be made. That effort represents a major portion of the total electrical system installation cost.

Standardization

The LX design accommodates several standardization philosophies, including those that have been developed by the Affordability Through Commonality (ATC) team at NAVSEA. These include the following:

- . Modular Sanitary Spaces. A separate effort has been undertaken by the ATC team to develop standardized, pre-outfitted, modular crew, CPO/NCO or officer sanitary space which will replace traditional sanitary spaces at designated locations within the LX.

- . Hatches, Scuttles, and Doors. Major openings will be of standard size and closures of standardized construction. Location of major openings also consider facilitation of equipment removal and installation.

- Standardized Space Arrangements. Replication of space arrangements was pursued within similar spaces such as the AFFF, CONFLAG, troop living, crew living, and fan rooms. Wherever possible, these spaces are identical in configuration, rather than the more traditional practice of having spaces on opposite sides of the ship be mirror images of one another. In addition to the reduction in

design and construction man-hours, this provides for standard operating procedures for each such compartment

. Stiffener Standardization. LX structural engineers made an analysis of the number of different stiffener sizes that were originally proposed in the structural drawings. They then reduced the number of different sizes by about 1/2, while remaining within the design constraints. Also, simpler stiffener shapes were used as alternatives to built-up members.

Machinery Space Arrangements

Throughout the PD phase, the PODAC Working Group reviewed and provided comments on machinery space arrangements to the cognizant Task Leader. The comments primarily related to the grouping of system components to facilitate a shipyard's ease in assembling machinery package units for installation as a unit on block or on board. Rearrangements were recommended for the purpose of locating equipment close to other related equipment, thus minimizing piping runs and conserving space.

CONTRACT DESIGN EFFORTS

Shipbuilder Involvement

During the Contract Design Phase, which began in FY '94, five shipbuilders were selected to participate by sending full time representatives to be collocated at the design site with the Navy Design Team. These representatives participated in weekly staff meetings of the design team and the separate weekly meetings of the Hull, Machinery and System Engineers

with their several Task Leaders. The shipyards have been funded to carry out about twenty different studies during the CD period to date. They participated in reading sessions and provided comments on the each draft of the Ship Specifications.

CONCLUSIONS AND RECOMMENDATIONS

The efforts of the Working Group were very well accepted by the members of the design team. The design of the LX at the end of the Preliminary Design period was a much more producible ship than it would have been without the establishment of the PODAC Working Group and the acceptance of their presence during the design period. All of the Task Leaders were very responsive to the recommendations of the Group and frequently initiated contact in order to obtain an opinion concerning the relative producibility of design alternatives that were being considered.

There was sincere interest by the design team in assuring the affordability of the design and numerous producibility improvements were generated by design team members independently of the Group. Credit for this must be given to the NAVSEA Ship Design Management from the top level to the LX Ship Design Manager, all of whom gave serious emphasis to this aspect of the design effort.

It is strongly recommended that a Producibility Task Manager be assigned in every NAVSEA design project. However, this assignment should not wait until the PD phase. On the LX project, the spacing of the transverse bulkheads was determined during the Feasibility Design phase and was essentially a given at the inception of PD. There had been no consideration to producibility aspects, such as the available steel plate lengths, when es-

establishing the bulkhead spacing. This aspect of the design might have been overridden by other design requirements, but it would not have been overlooked if a Producibility Task Manager had been assigned during the feasibility study.

while the products required of this effort could have been comfortably accomplished with the traditional pen and paper approach, the PODAC Working Group decided to use the digital data being developed by the individual design disciplines to the greatest extent practicable. This was intended to keep the products of the Working Group effectively tied to the evolving ship design and minimize the data or drawing maintenance requirements that would have been necessary to keep up with those changes. It was also felt that this might allow some additional future capability to analyze the products. This was only partially realized. Therefore, it is concluded that the CAD system that is to be used for the development of early stage ship design products must include provisions for the production planning functions necessary to develop and implement a GBS. This will ensure that production specific information that is placed in that database is available to all designers, and that production constraints may be imposed on the designers where necessary.

The GBS Study conducted during the LX Preliminary Design only addressed a few aspects of the Hull, Mechanical and Electrical (HM&E) systems design and production. In addition, to be complete, the study should have included Combat Systems design and production and total ship integration. Therefore, it is recommended that the continued studies of the GBS concept be expanded to include all HM&E systems as well as combat systems and the integration of these systems and equipment.

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